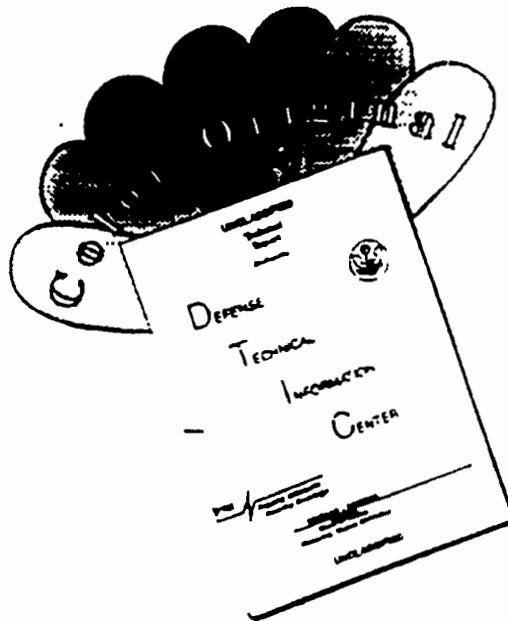


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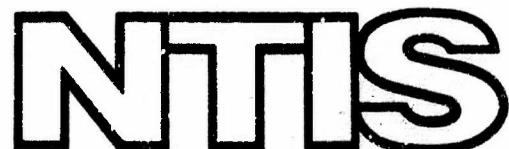
COMBUSTION OF MIXED "HOMOGENIZED"
SYSTEM

Yu. V. Frolov, et al

Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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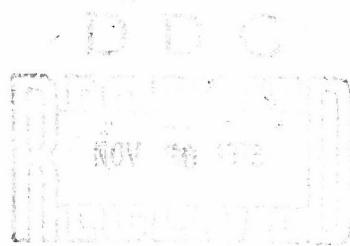
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COMBUSTION OF MIXED "HOMOGENIZED" SYSTEM

by

Yu. V. Frolov, A. I. Korotkov,
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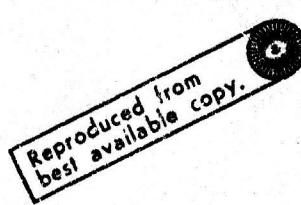
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COMBUSTION OF MIXED "HOMOGENIZED" SYSTEMS

Yu. V. Frolov, A. I. Korotkov, and
V. F. Dubovitskiy

Moscow

The combustion of mixed condensed systems depends on a number of parameters, including the dispersity of the components [1].

A mixture of readily decomposing combustible and oxidizer has two limiting cases: a) combustion along the oxidizer and combustible grain interface; b) a kinetic regime of homogeneous gas mixture combustion (of premixed decomposition products). The first condition is fulfilled, when the zone of complete mixing of the gasification products of the initial components (h) is much greater than the zone of their heating to the temperature of the beginning of the reaction (l). The second regime exists with the opposite relationship between h and l . In both cases the rate of normal flame front propagation increases practically linearly with pressure. Contact combustion is characteristic for high pressures and large oxidizer particle dimensions; homogeneous combustion for finely dispersed systems and low pressures.

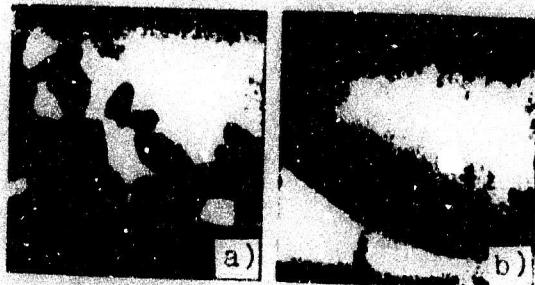


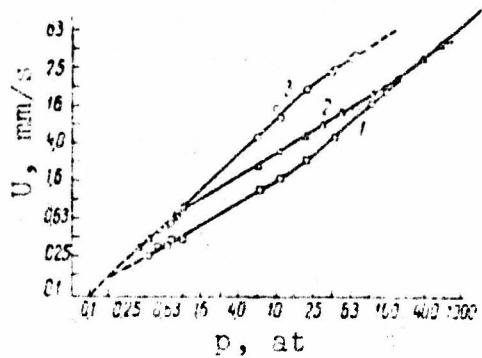
Fig. 1. Motion picture frames of the combustion of a stoichiometric APC-saccharose system:
 a) APC particle dimensions $d_{OK} = 200-300 \mu\text{m}$ (photograph of the end plane; b) $d_{OK} < 2 \mu\text{m}$.

Figure 1 shows high-speed motion picture frames, which illustrate the combustion of a mixed stoichiometric ammonium perchlorate (APC)-saccharose system in the two limiting cases.

The contact combustion regime of the mixture with the oxidizer $d_{OK} \approx 200-300 \mu\text{m}$ is shown in Fig. 1a. Between the individual APC and the saccharose crystals burnt places are distinctly visible; they form a highly developed combustion surface. The flame front consists of individual bright tongues of flames merging into one. In contrast to this mixture the composition with the components $d_{OK} < 2 \mu\text{m}$ in the low pressure range has a very flat surface (Fig. 1b). A "dark zone" immediately adjoins it, whose dimensions decrease sharply with pressure. A high-temperature luminous flame zone is situated above.

However, in the most general case continuity [2, 3] exists between the indicated limiting combustion regimes of the condensed mixtures. With a variation in pressure the contact combustion regime can go over into the homogeneous combustion regime and vice versa. The transition condition is determined by the variation in the relationship between the mixing zone and the reaction zone. The transition process is gradual. Its boundary with respect to pressure depends on the dispersity of the components: the smaller

a particle is the more it is displaced in the high pressure range and vice versa. Figure 2 shows the dependences of normal combustion rate on the pressure of the APC-saccharose system for three different degrees of component mixing. It is easy to see, that for laminar system (1) the disruption range for contact combustion begins approximately in the region of 20 at and below (the homogeneous combustion range begins when $p \leq 0.1$ at). At the same time, for a mixture with finely ground components (3) the disruption of the homogeneous combustion regime (the range of purely contact combustion, apparently, sets in at pressures above 5000-7000 at) occurs in this same pressure range. The rules governing purely contact combustion (the combustion of laminar systems) were examined in detail in work [4]. Below, we will focus our main attention on the combustion of "homogenized" systems obtained by prolonged joint grinding of the components in a medium of inert liquid on a vibration stand (the diameter of the particles is less than 2 μm).



*Fig. 2. The dependence of the combustion rate of a stoichiometric APC-saccharose mixture on pressure: 1 - laminar system (layer thickness of 140 μm); 2 - $d_{0K} \approx 10$ μm ; 3 - $d_{0K} < 2$ μm .

The combustion of similar types of "homogenized" systems takes place at a rate attaining 25-35 mm/s and more (at a pressure of 30-40 at). The fact of the increase in combustion rate with reduction in particle diameter is known [1]. However, the fact, that the combustion rate at such a degree of pulverization of the components exceeds by 4-5 times the combustion rate of similar systems with the conventional employed dispersity of the components ($d = 20-100$ μm) is very remarkable and considerably extends the limits of the variation in the normal combustion rate of mixed systems exclusively only due to the variation in particle dimensions.

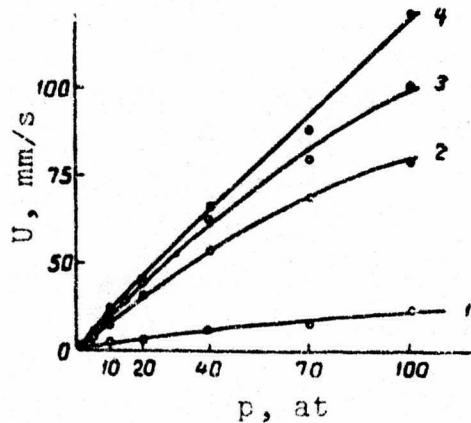


Fig. 3. The dependence of the combustion rate of an APC-urotropin mixture on pressure: 1 - $d_{0K} = 140-320 \mu\text{m}$; 2 - $d_{0K} < 2 \mu\text{m}$; 3 - APC-urotropin (80/15) + 5% Fe_2O_3 ($d_{0K} < 2 \mu\text{m}$); 4 - APC-urotropin (75/15) + 10% Al ($d_{0K} < 2 \mu\text{m}$).

It has already been indicated above, that the surface and the combustion front of "homogenized" mixtures are to a considerable extent uniform. This makes these types of mixtures very attractive for the carrying out of different types of thermophysical measurements, for ascertaining the peculiarities of the effect of catalytic agents, and finely dispersed metals, etc., on the combustion process. Fig. 3 demonstrates the effect of the catalytic agent Fe_2O_3 and of finely dispersed aluminum on the combustion rate of a model APC-urotropin mixture. In spite of the high level of the normal combustion rate of the original system ($d_{0K} < 2 \mu\text{m}$) the presence of a catalytic agent introduced into the mixture during the stage of component mixing, increases the combustion rate. In this case the activity of the catalytic agent increases with pressure: in the 70-100 atm pressure range the increase in rate due to the introduction of the catalytic agent is 30-35%. This fact shows, that even under the conditions of a fast-burning system the catalytic agent is not an inert material, but is capable of actively affecting the combustion process. The effect from the introduction of aluminum into the composition of "homogenized" systems is also considerable. Upon the introduction of 10% finely dispersed aluminum into a APC-urotropin system the combustion rate of the composition increases by 1.4-1.7 times. Detailed investigations have shown, that the aluminum particles begin to ignite practically on the combustion surface of the sample. On the one hand, the actual absence of the agglomeration of metal particles

on the combustion surface (or close to it), and on the other hand - the proximity to the combustion surface and the homogeneity of the high-temperature flame zone, to a specific degree, promote this. The low level of metal agglomeration on fast-burning compositions once again emphasizes the role of combustion rate as one of the determining parameters in the phenomenon of enlarging the particles of a metallic additive and agrees with the general rules governing this phenomenon [5].

The general characteristics of the combustion zones of "homogenized" systems were obtained, besides with the use of motion picture photography, by employing thin flat thermocouples (5 μm). The application of these was justified, since the characteristic dimensions of the system are less than the dimensions of the thermocouples, but at increased pressures is connected with specific difficulties caused by the thermal retardation of the thermocouple as a result of the high combustion rates. The temperature of the combustion surface of a stoichiometric APC-saccharose mixture ($d_{\text{ок}} < 2 \mu\text{m}$) is equal to 520°C at atmospheric pressure and 540°C at 5 at. $T_{\text{ок}}$ lies in the $2400-2600^\circ\text{K}$ range and is close to the value of the zone temperature determining the combustion rate and calculated in accordance with coefficient β : $T_{\text{ок}} = \sqrt{E/2h\beta}$ [6]. The magnitude of β in the range of initial T (from -40 to $+50^\circ\text{C}$) and p ($10 + 50$ at) does not (or weakly) depends on p and for the investigated systems is equal to $(1.5-2.2) \cdot 10^{-3} \text{ deg}^{-1}$.

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